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Storm-wave development of shore-normal grooves (gutters) on a steep sandstone beach face

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ABSTRACT

Shore-normal grooves (gutters) cut into the seabed have been reported widely from the marine geological record. Grooves commonly are spaced regularly across plane, consolidated surfaces in the littoral and sub-littoral zones and may be deeply incised. Despite their common occurrence in the rock record, there are few detailed descriptions of examples from modern environments. Previously reported examples have been ascribed to erosion by wave-induced currents, especially storm-driven near-shore flows. In particular, examples from beach faces have been related to either wave swash or backwash. However, no conceptual model exists to explain the presence of grooves, their morphology or their spacing alongshore.

Herein, quasi-regularly spaced grooves on a soft sandstone beach face are described and interpreted to have formed due to wave breaking and swash zone processes consequent upon exceptional storms at sea. The groove morphologies are quantified using terrestrial laser scanning. Numerical modelling of the translation from offshore waves to nearshore breaking waves provides estimates of the swash zone parameters. A consideration of swash zone processes provides an explanation for formation of the grooves. In particular, the swash zone shear stress distribution and consequent bed erosion is a dome-shaped function of distance across the beach face, and this controls the cross-shore variability in groove depths. High-speed sheet flows, such as swash and backwash, develop periodic, shore normal, high and low speed streaks alongshore. Consequent streaky erosion produces the quasi-regular alongshore groove spacings. However, on any given beach face the specific spacing of grooves is likely a property, not only of the local sheet flow attributes, but also of larger-scale morphological forcing. This outcome suggests that spacing is an emergent property of the coupled sheet flow and larger-scale forcing, and thus specific spacings on any beach face remain unpredictable.

1. Introduction

Linear erosional bedforms cut into soft bedrock have been reported widely from the marine geological record, albeit with different descriptive names (*e.g.* furrows, grooves, gutters, runnels). The terms ‘groove-cast’ or ‘gutter-cast’ have been applied widely to the sedimentary fill within reported examples (*e.g.* Birkenmajer, 1958; Whitaker, 1973; Myrow, 1992). The bedforms are usually relatively long, straight or weakly sinuous but otherwise parallel (Allen, 1982), and spaced more-or-less regularly across fairly plane surfaces at intervals of a few decimetres to a few metres. The incisions may be deep (< 1 m) with vertical and overhanging sides (Plint, 1991; Plint and Norris, 1991; Myrow, 1992; McKie, 1994; Plint and Nummedal, 2000; Plint and Cheadle, 2015). Plint and Norris (1991) and Shank and Plint (2013) loosely apply the term ‘gutter’ to offshore examples and the term ‘groove’ to near-shore examples. Consequently, the term groove is adopted in the following text. In the littoral geological record, grooves are usually shore-normal (Plint and Norris, 1991; Plint and Nummedal, 2000) and have been ascribed to erosion of the substratum by reversing wave-induced currents (Plint and Norris, 1991; Duke, 1990; Beukes, 1996), especially during storms (Hiscott, 1982; Plint, 1991; Plint and Nummedal, 2000). Similarly, Aigner (1985) invoked reversing flows as the formation mechanism for sub-littoral grooves that he hypothesized were due to storm wave-induced return-flows. Thus, these various grooves are believed to align roughly parallel to wave swash, backwash or surf currents.

Despite their common occurrence in the rock record, grooves can have disparate origins (Myrow, 1994) and so it is important for

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environmental reconstruction to detail modern examples to aid discrimination of the depositional context. In the case of modern beaches, there are relatively few published examples and all are developed on consolidated substrata (soft bedrock) within littoral and sub-littoral locations subject to variable wave-energy levels (*e.g.* Groba, 1959; Seibold, 1963). Grooves are usually less than a metre apart and less than a metre deep (*e.g.* Plint, 1991; Plint and Nummedal, 2000). Allen (1982) and Otvos (1999) report examples of erosional grooves with spacings of 1 m or less from both modern and ancient beach faces that are ascribed to wave swash, whereas Evans (1938) and Hawkes (1962) related such features to backwash. Allen (1982) was unable to account for the spacing of the beach face grooves, which he inferred was due to concentration of swash into shore-normal parallel zones. Shank and Plint (2013) illustrate elongate grooves on near-shore ravinement surfaces cut in sandstone and mudstone; these may have steep, vertical or overhanging margins, but these grooves do not appear to exhibit a regular longshore spacing.

Herein, grooves are reported that were observed in soft sandstone on a steep beach face, which was exposed by storm wave action stripping the overlying shingle (flattened pebble layer). The beach is at Medmerry, in southern England (Fig. 1). Although no near-shore hydrodynamic data were collected during the event, simulations of wave run-up on the beach face for known offshore conditions are placed within a theoretical framework and are used to propose a model for groove formation. This framework is used to test the hypothesis that groove morphology reflects the beach face wave-induced sheet flow processes within the swash zone.

1.1. Study site at Medmerry, south coast of England

An aerial view of the study area from the Channel Coastal Observatory (CCO; www.channelcoast.org) from July 2014 shows the site after the winter storms of 2013–2014 (Fig. 1). The inland wetland to the west is artificial; an UK Environment Agency conservation project associated with a new artificial breach in the foreshore. Highlighted on the image are beach profile locations referred to below, the breach location, gravel overwash deposits and the area of grooves examined in this paper.

1.1.1. Geology of the Medmerry beach face

The Medmerry foreshore consists of soft sandstone in three formations of the Eocene Bracklesham Group shallow marine deposits, with a thin covering of shingle. These brackish-water deposits constitute primarily of glauconitic, fine to medium, thick-bedded sandstone rich in clay and silt. They contain marine shells, specifically *Ostrea* and large *Pholas crispate* (*L.*). Several accounts provide detail of the Bracklesham Group (Curry et al., 1977; Edwards and Freshney, 1987; Plint, 1988; Bone and Tracey, 1996; King, 1996; Daley, 1999; Aldiss, 2002) but here the formation nomenclature of Curry et al. (1977) is adopted. The lower Wittering Formation (Units W7–W9: Curry et al., 1977; Plint, 1988) is rarely exposed, whereas the beach face exposes *circa* 8 m thickness of the Earnley Formation (Units E9-E12: Curry et al., 1977). The upper foreshore (shorewards of the gravel overwash – Fig. 1) consists predominately of the Selsey Formation (Units S4-S7: Curry et al., 1977).

The shoreline has been retreating throughout the late 19thC and

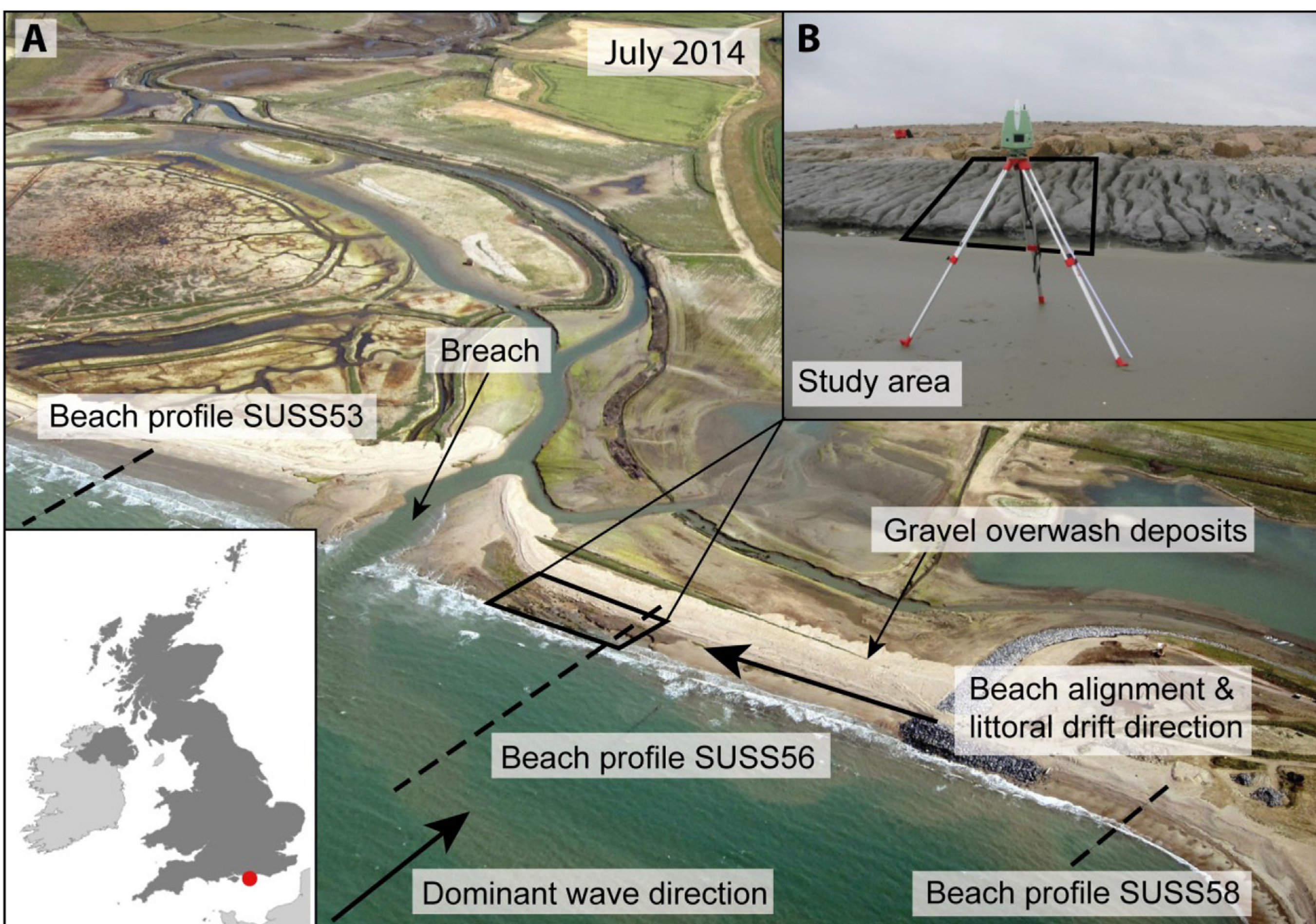

Fig. 1. A) Aerial view looking to the north of the Environment Agency Medmerry managed realignment breach site, July, 2014 (CCO), showing the location of the study site (circa N 50°44′ 30.70''; E 0° 49′ 19.26″) and beach profile used in the modelling. Inset (B) shows the study area and grooves being laser scanned (see Method).